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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 744

Contribution from the Bureau of Animal Industry
JOHN R. MOHLER, Chief

Washington, D. C. PROFESSIONAL PAPER January 17, 1919

COOLING MILK AND STORING AND SHIPPING IT AT LOW TEMPERATURES

By

JAMES A. GAMBLE, Market Milk Specialist, and
JOHN T. BOWEN, Technologist, Dairy Division

CONTENTS

	Page
Scope of Experimental Work	1
The Principle of Cooling	1
Cooling Milk on the Farm	4
Effect of Low Temperatures on Bacterial Count of Milk	4
Cooling Efficiency of Various Kinds of Tanks	5
The Construction of Milk Tanks	15
How to Cool Milk Quickly	18
Efficiency of Different Kinds of Cans for Holding Milk	21
Transporting Milk at Low Temperatures	24
Summary	28

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SCOPE OF EXPERIMENTAL WORK.

The experimental work reported in this bulletin covers (1) the relative efficiency of cooling tanks of different construction handled under varying conditions; (2) the most efficient methods of cooling and storing milk on the farm; and (3) the transportation of milk at low temperatures to market.

THE PRINCIPLE OF COOLING.

If a warm body is placed in contact with a cold one, heat will flow from the warmer to the colder until both have reached the same temperature. The rate of this flow depends upon the difference of temperature between the two bodies. Heat flows most rapidly when there is the greatest difference in temperature, and the rate gradually decreases as the temperatures become equal.

The temperature of a body does not give a true indication of the amount of heat it contains. Heat is commonly measured by a unit called the British thermal unit, usually abbreviated B. t. u., which is the heat necessary to raise the temperature of 1 pound of water 1° F. The reason that the heat required to raise 1 pound of water 1° F. is taken as the unit is because water is one of the most difficult of all substances to heat. Practically all other substances require less heat to raise a unit quantity 1° F. For example, the heat necessary to raise 10 pounds of iron 100° F. is only $10 \times 0.113 \times 100 = 113$ B. t. u. In other words, while it takes 1 B. t. u. to raise 1 pound of water

1° F., it takes only 0.113 B. t. u. to raise 1 pound of iron 1° F. The specific heat of a substance is its ability or capacity, compared with water, to absorb heat.

All substances in nature contain more or less heat, but no way has been found for abstracting all the heat contained. In practice, however, we are not concerned with the total amount of heat a body may contain but with the changes that occur in the quantity; that is, how much heat is added or subtracted in raising or lowering the body through a given range of temperature. This is found by multiplying the weight of the body in pounds by its specific heat and then multiplying the product by the number of degrees change in temperature. For instance, if 100 pounds of warm water were cooled 100° F. the heat given up would be $100\times1\times100=10{,}000$ B. t. u.

The average specific heat of milk which contains $3\frac{1}{2}$ per cent butterfat is 0.93; therefore, the amount of heat required to raise 100 pounds of such milk 50° F. is $100\times0.93\times50=4{,}650$ B. t. u. If a like quantity of milk is cooled the same number of degrees, the B. t. u. given up are the same. In other words, the calculations are identical whether milk is heated or cooled.

Air and water are two natural cooling agencies. Cooling by means of air is not generally practicable because of its low heat-absorbing capacity and because its temperature is usually too high. Water, therefore, is the common cooling agency used. If it were possible to avoid all losses, 1 pound of milk in being cooled 1° F. would require 0.93 of a pound of water which would be raised 1° F. in temperature. In practice, however, a certain amount of cooling effect is always lost through radiation; consequently more water will be required, the exact quantity depending upon the efficiency of the cooling apparatus. This is assuming that the cooler was 100 per cent efficient. To determine the final temperature when milk is cooled by water and allowed to remain until both are practically the same temperature the following formula may be used:

$$t=\frac{(W\times S\times T)+(W_1S_1T_1)+(W_2S_2T_2)}{WS+W_1S_1+W_2S_2}$$

t=Final temperature of whole.
W=Weight of water.
S=Specific heat of water.
T=Initial temperature of water.
W_1=Weight of milk.
S_1=Specific heat of milk.
T_1=Initial temperature of milk.
W_2=Weight of can.
S_2=Specific heat of can.
T_2=Final temperature of can.

For example, figure 1 shows a 10-gallon can of milk at an initial temperature of 85° F. being cooled in a tank containing 30 gallons of water at an initial temperature of 37° F. The weight of the can containing the milk is taken at 21 pounds and its temperature is approximately that of the milk, 85° F. The weights of the water, milk, and can are 250, 86, and 21 pounds, respectively, and their specific heats are 1, 0.93, and 0.113, respectively. Substituting these in the formula above and solving for the final temperature of the whole, we have:

$$t=\frac{(250\times 1\times 37)+(86\times 0.93\times 85)+(21\times 0.113\times 85)}{(250\times 1)+(86\times 0.93)+(21\times 0.113)}=\frac{16252}{332.4}=48.9^\circ \text{ F.}$$

In practice, however, some heat is absorbed in the surrounding air so that the final temperature of milk and water is higher than that given in the formula. In other words, the final temperature as calculated must be divided by the per cent efficiency of the tank. The efficiency of a good insulated tank of the size and construction of that shown in figure 1 was found to be about 97 per cent. The final temperature of the milk and water will, consequently, be 48.9 divided by 0.97 or 50.4° F.

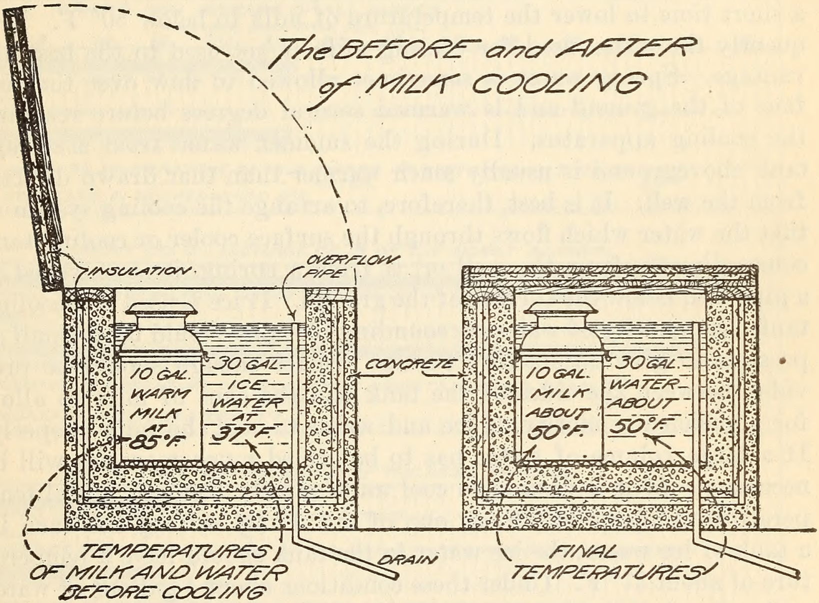
The BEFORE and AFTER of MILK COOLING
INSULATION
OVERFLOW PIPE
10 GAL. WARM MILK AT 85°F
30 GAL. ICE WATER AT 37°F
CONCRETE
10 GAL. MILK ABOUT 50°F
30 GAL. WATER ABOUT 50°F
TEMPERATURES OF MILK AND WATER BEFORE COOLING
DRAIN
FINAL TEMPERATURES

FIG. 1.—Initial and final temperature of milk and water in a concrete-insulated cooling tank.

Ice is usually necessary in order to lower the temperature of water to a point at which it will cool milk quickly and efficiently. One pound of ice has many times the cooling capacity of an equal weight of water at an initial temperature of 37° F. To change the temperature of 1 pound of water 1 degree requires the addition or extraction of only 1 B. t. u. To freeze 1 pound of water, however, requires the extraction of 144 B. t. u. In the process of freezing 1 pound of water 144 B. t. u. are extracted without change in temperature. In the melting of ice the reverse is true. This phenomenon is called the latent heat of fusion of ice. The heat required to melt 1 pound of ice, therefore, is sufficient to raise 1 pound of water 144° F. or 144 pounds of water 1° F.

COOLING MILK ON THE FARM.

Milk may be cooled most efficiently on the farm by running it over a surface cooler in which the available water supply is used at its coldest temperature and the cooling completed by storing the cans of milk in a tank of ice water. It is possible in that way within a short time to lower the temperature of milk to below 50° F. Frequently the water used for cooling milk is not used to the best advantage. Spring water is sometimes allowed to flow over the surface of the ground and is warmed several degrees before reaching the cooling apparatus. During the summer water from a storage tank aboveground is usually much warmer than that drawn directly from the well. It is best, therefore, to arrange the cooling system so that the water which flows through the surface cooler or cooling tank comes directly from the well or, if from a spring, it is conveyed in a pipe well below the surface of the ground. If ice is used in a cooling tank the quantity of water surrounding the cans should be as small as possible to give satisfactory results. Space enough should be provided between the sides of the tank and the cans of milk to allow for a sufficient quantity of ice and water to cool the milk properly. If a large volume of water has to be cooled much more ice will be necessary. If it is desired to cool milk quickly from an initial temperature of about 85° F. to one of 50° F. by setting the cans in a tank of ice water, the ice water in the tank should have a temperature of about 37° F. Under these conditions about 4 gallons of water will suffice for each gallon of milk.

EFFECT OF LOW TEMPERATURES ON BACTERIAL COUNT OF MILK.

It is commonly recognized that high bacterial counts in market milk are due largely to multiplication of bacteria rather than to inoculation. It is interesting, therefore, to note the effect of low temperatures in reducing the bacterial content of market milk. A survey of dairies in New England where high bacterial counts in the milk had been obtained was followed by instructional work emphasizing the importance of rapid and efficient cooling and demonstrating the best method of cooling at the least expense. A later survey illustrates the effect that prompt cooling and holding the milk at low temperatures had upon the bacterial content (fig. 2).

The average temperature of all samples of milk taken before the educational work was 62° F. and the average after the educational work was 54° F., or a drop of 8 degrees. The average bacterial count before was 27,000,000 per cubic centimeter, while after the instruction was given it was only 750,000 per cubic centimeter. In 18 of the poorest dairies the average bacterial count was 63,000,000 per cubic centimeter before and 2,600,000 after. The temperature before instruction was given was 63° F. while the temperature after was 56° F. Fifty-one of the best dairies had an initial count of 15,370,000 per cubic centimeter while after the demonstration the count was reduced to 170,000 per cubic centimeter, a decrease of 15,200,000 per cubic centimeter. This decrease was due largely to the prevention of multiplication of bacteria because the milk was kept at a lower temperature. These examples serve to illustrate how important prompt cooling on the farm is in keeping down the bacterial count of market milk.

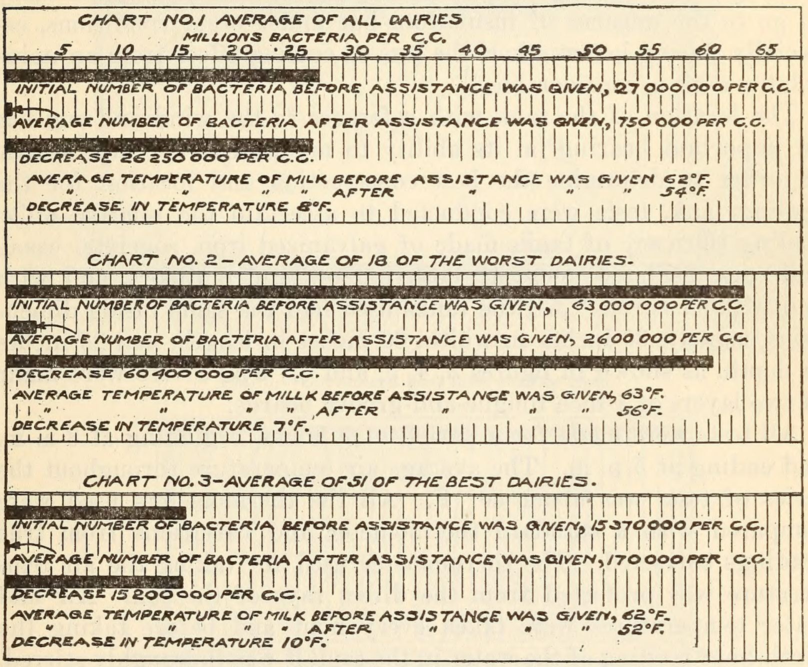

FIG. 2.—Showing improvement in milk supply of 102 New England dairies after assistance by U. S. Departure of Agriculture.

COOLING EFFICIENCY OF VARIOUS KINDS OF TANKS.

In order to cool and hold milk at low temperatures on the average farm a properly constructed cooling tank is necessary. In fact most dairy farms have some sort of tank in which water or water and ice are used to cool and store milk. According to a recent questionnaire approximately 80 per cent of the dairy farms producing market milk use some sort of cooling tank. The total number of dairies that reported approximated 40,000, located in 32 States. Nineteen per cent of the tanks were reported to be of metal, 25 per cent of wood, 31 per cent of concrete, and the construction of the remaining 25 per cent was not mentioned. Very few tanks were insulated, and in most cases no effort was made to minimize the loss of cooling effect due to the surface of the tank. When an abundant supply of cold running water continually passes through the tank it is unnecessary to go to the expense of insulation, but under other conditions, especially during hot weather, the loss of cooling effect from an uninsulated tank is considerable.

The location of the tank with reference to the wind and sun has an important bearing on its ability to maintain low temperatures. In order to determine the best construction and location for the cooling tank, tests were conducted to ascertain the relative milk-cooling efficiency of tanks made of galvanized iron, concrete, wood, and cork-insulated material, both indoors and outdoors, and with and without covers. All the tanks used had the same inside dimensions, namely, 30 inches in width, 60 inches in length, and 25 inches in depth, as shown in figures 3, 4, 5, and 6. The covers were made of two layers of $\frac{7}{8}$-inch tongue-and-groove boards.

All tests were made for a period of 9 hours, beginning at 8 a. m. and ending at 5 p. m. The average air temperature throughout the series of tests was about 80° F. All the thermometers used were compared with a standard thermometer and variations from true readings corrected. The thermometer used for taking the air temperature was protected from the direct rays of the sun. Air and water temperatures were taken every hour and before taking the ninth-hour reading of the water in the tank it was thoroughly stirred. Each tank contained 1,100 pounds of water at an initial temperature of 54° F.

The conditions of the tests were in brief as follows: In test No. 1 the tanks were left uncovered and set side by side in the sun. The average air temperature for the 9 hours was 84.2° F. In test No. 2 the tanks were covered and the air temperature averaged 83.5° F. In test No. 3 the tanks were sheltered from the sun by a building and were uncovered. The average air temperature was 85.2° F. In test No. 4 the tanks were sheltered by a building, were covered, and at an average air temperature of 83.4° F. Except as noted all conditions were similar for each test.

Figures 7 to 10, inclusive, show the curves of the change in temperature of the air and water under the various conditions of the

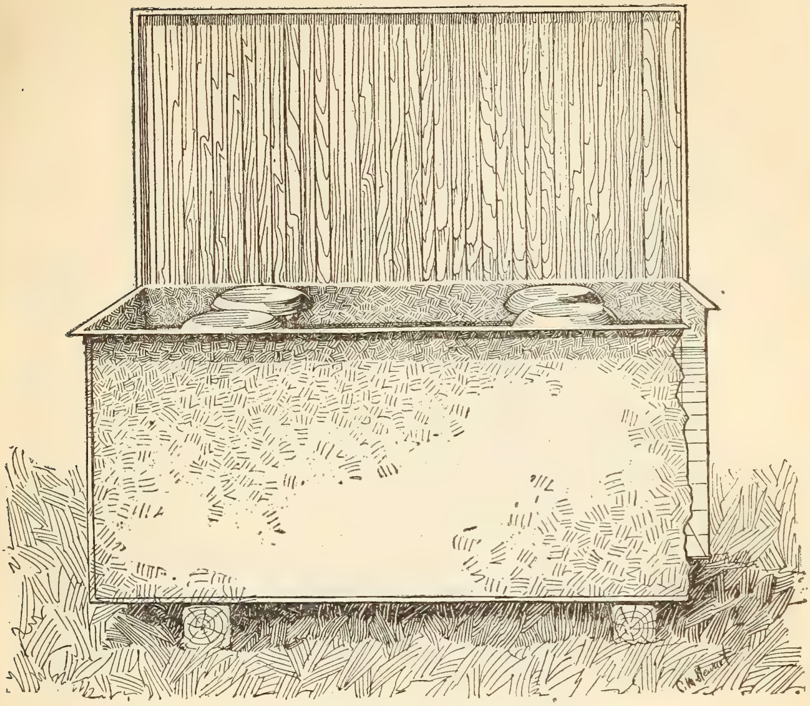

FIG. 3.—Galvanized-iron milk-cooling tank.

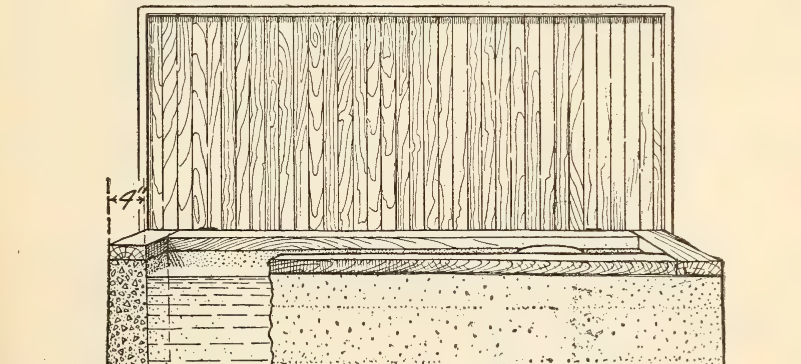

FIG. 4—Concrete milk-cooling tank.

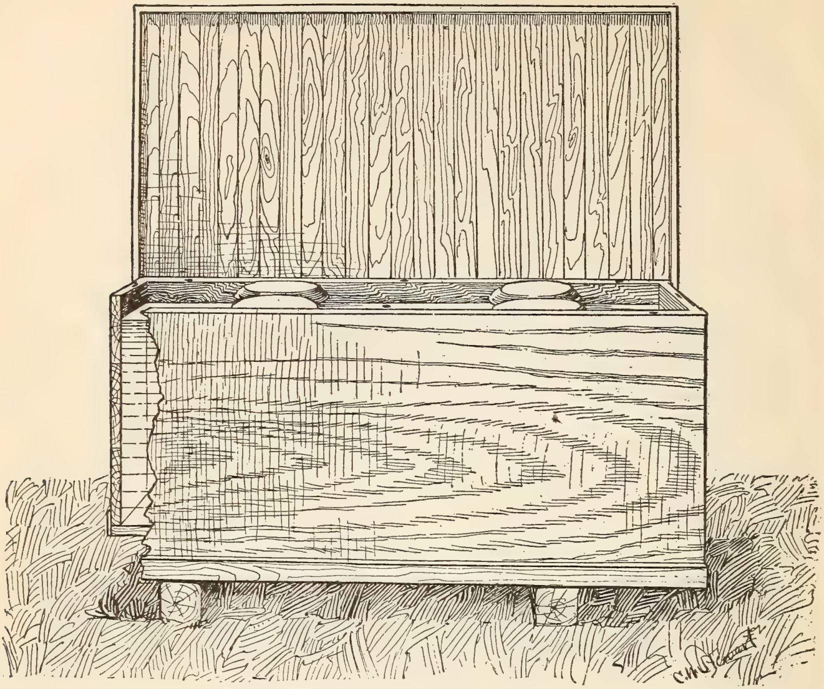

FIG. 5.—Wooden milk-cooling tank.

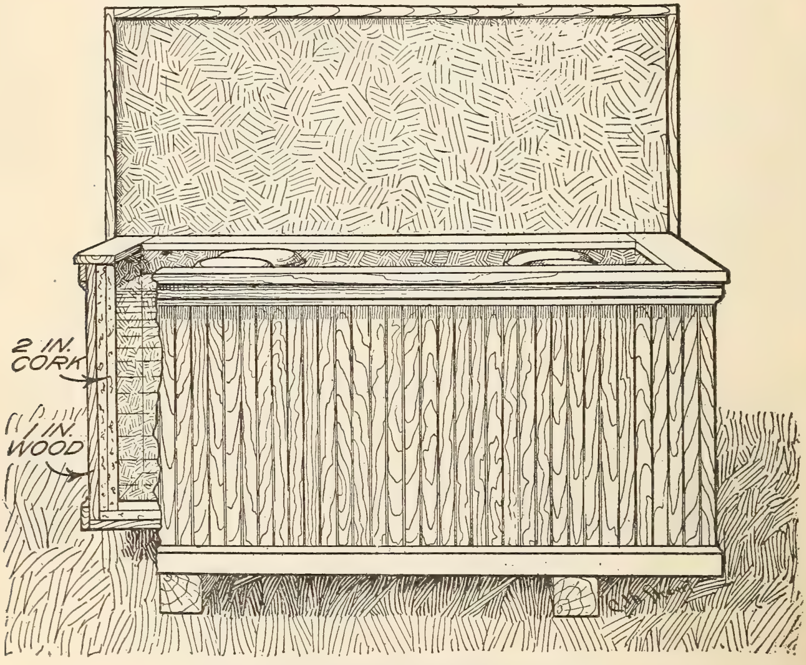
2 IN.
CORK
1 IN.
WOOD

FIG. 6.—Cork-insulated milk-cooling tank.

four tests. Table 1 shows the B. t. u. absorbed under the different conditions:

TABLE 1.—*B. t. u. absorbed by water and tanks under different conditions.*

Type of tank.	Outdoors.		Indoors.	
	Uncovered.	Covered.	Uncovered.	Covered.
	B. t. u.	*B. t. u.*	*B. t. u.*	*B. t. u.*
Galvanized iron	24,200	15,950	15,400	12,100
Concrete	19,800	12,650	11,550	8,800
Wood	15,400	5,500	7,150	4,400
Insulated	11,550	1,650	4,400	1,100

Table 2 shows the relative loss of efficiency in cooling tanks of different construction compared with the insulated tank.

TABLE 2.—*Relative loss of efficiency in cooling tanks of different construction, based on the insulated tank as unity.*

Type of tank.	Outdoors.		Indoors.	
	Uncovered.	Covered.	Uncovered.	Covered.
Galvanized iron	2.1	9.7	3.5	11
Concrete	1.7	7.7	2.6	8
Wood	1.3	3.3	1.6	4
Insulated	1	1	1	1

The relative loss of cooling effect in tanks of different construction expressed in pounds of ice is shown in Table 3. This table also emphasizes the range of loss in cooling effect through radiation from cooling tanks during hot weather.

TABLE 3.—*Relative loss in cooling effect in tanks of different construction expressed in pounds of ice.*

Type of tank.	Outdoors.		Indoors.	
	Uncovered.	Covered.	Uncovered.	Covered.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Galvanized iron	168	111	107	84.0
Concrete	137	88	80	61.0
Wood	107	38	50	30.5
Insulated	80	12	30	7.6

The galvanized-iron tank, without a cover and exposed to the direct rays of the sun, lost 168 pounds of ice compared with 7.6 pounds of ice for the cork-insulated tank covered and sheltered, or a difference of 160.4 pounds of ice. A loss of this amount of ice each day for 150 days would amount to approximately 24 tons for the season. At that rate, in 150 days the loss of ice, estimated at 15 cents a hundredweight, would be $72. Frequently ice costs more than the price named, which would add to the saving effected by an insulated tank. While few dairymen would waste so large a quantity of ice, the result indicates the economy of using a covered, insulated tank.

Four other tests were conducted with the same tanks under best service conditions. All tanks were covered and sheltered. The galvanized-iron, concrete, and wooden tanks each contained 1,000 pounds of water at 54° F., a 100-pound block of ice, and a 10-gallon can of warm milk; the cork-insulated tank contained the same quantity of water and ice and two 10-gallons cans of milk. In each case the block of ice was placed close to the can in order that the milk might receive its immediate cooling effect. The water in the tank was slightly stirred each hour, after which the temperature reading was taken. The milk was not stirred during any of the tests; the results of the tests are shown in figure 11.

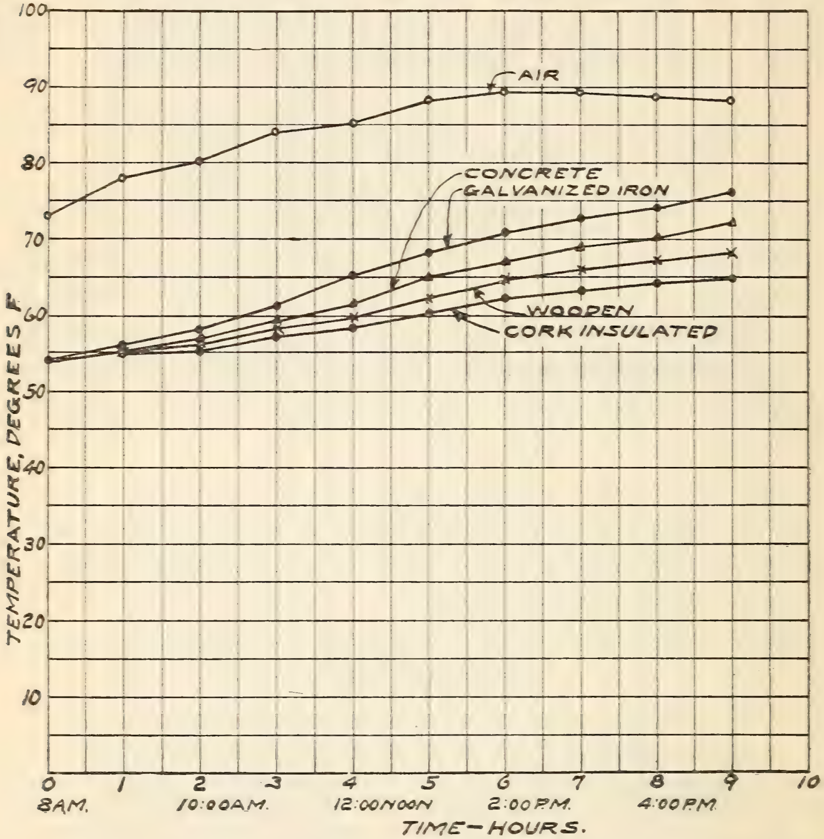

FIG. 7.—Rise in temperature of water during 9 hours in 4 types of cooling tanks. All tanks uncovered and exposed to direct rays of sun.

During the test with the galvanized-iron tank the air temperature ranged from 72° to 80° F. with an average of 76° F. At the end of nine hours the temperature of the water was 58° F. and the temperature of the milk was 56.5° F. It will be noted that the minimum temperature of the water was reached three hours after the ice was added, and from that time on the temperature of the water rose slightly for the next two hours, until all the ice was melted. From this point the rise in the temperature of the water was more rapid. The temperature of the milk continued to fall until just before the sixth hour, when the curves showed that the temperature of the milk dropped below the water. This was due to the fact that about one hour before all the ice was melted the temperature of the water began to rise and rose faster than the temperature of the milk dropped. This is caused by the fact that there is a double transfer of heat, first from the air to the water, then from the water to the milk.

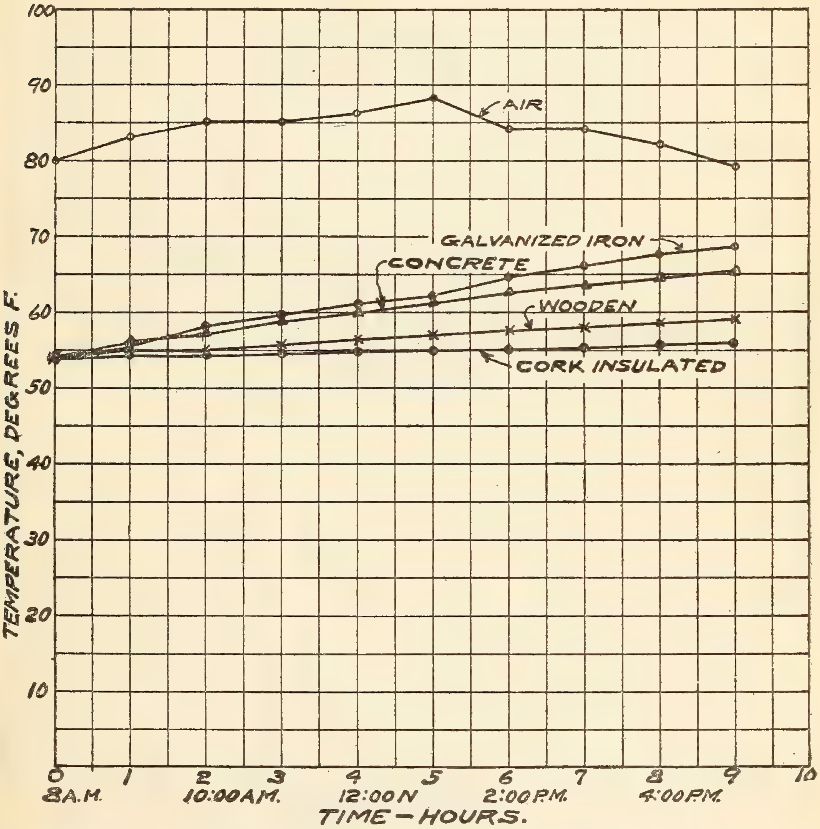

FIG. 8.—Rise in temperature of water during 9 hours in 4 types of cooling tanks. All tanks covered and exposed to direct rays of sun.

In the case of the concrete tank the air temperature ranged from 72° to 85° F. with an average of 79.4° F. or 3.4 degrees higher than in the case of the galvanized-iron tank. Notwithstanding this fact the final temperatures of the water and milk were 3 degrees lower in the concrete tank.

In the test of the wooden tank the air temperature ranged from 79° to 85° F. with an average of 81.1° F. for the 9-hour period. At the end of the test the tank-water had a temperature of 50.5° F. and the milk was 49.5° F. Notwithstanding the fact that the average air temperature was 5½ degrees higher than in the case of the galvanized-iron tank and 1.7 degrees higher than in the case of the concrete tank, the temperatures of the water and milk at the end of the test were 5½ degrees lower than in the concrete tank and 8½ degrees lower than in the galvanized-iron tank. This again illustrates the superiority, from the milk-cooling standpoint, of a wooden tank over either concrete or galvanized iron.

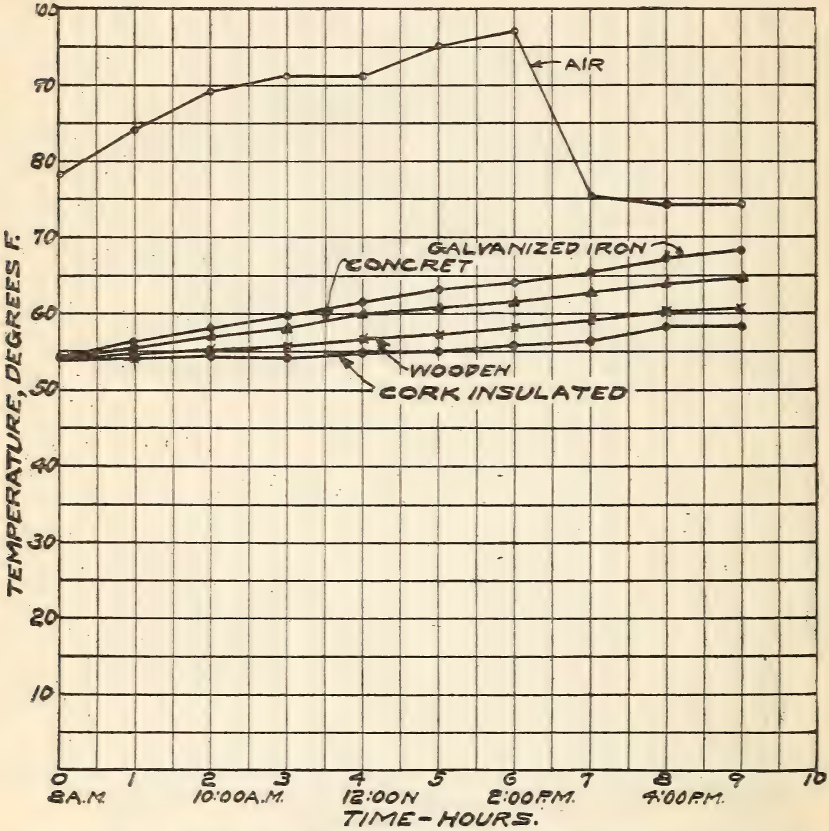

FIG. 9.—Rise in temperature of water during 9 hours in 4 types of cooling tanks. All tanks uncovered and in milk house.

The range of air temperature during the test of the cork-insulated tank was from 78° to 95° F. and averaged 89.3° F. Two 10-gallon cans of warm milk were placed in the tank instead of one, as in the foregoing tests. At the end of nine hours the temperatures of the tank-water and the milk were approximately the same, namely, 49° F. It will be noted, however, that at no time during the test did the temperature of the water rise above that of the milk, and it will be further noted that all the ice was not melted until the end of the sixth hour. The cork-insulated tank withstood an air temperature 13.3 degrees higher than the galvanized-iron tank, 9.9 degrees higher than the concrete tank, and 8.2 degrees higher than the wooden tank, and cooled two cans of milk instead of one to a lower temperature than any of the other tanks. The final temperature of the water in the insulated tank was 9 degrees lower than in the iron tank, 6 degrees

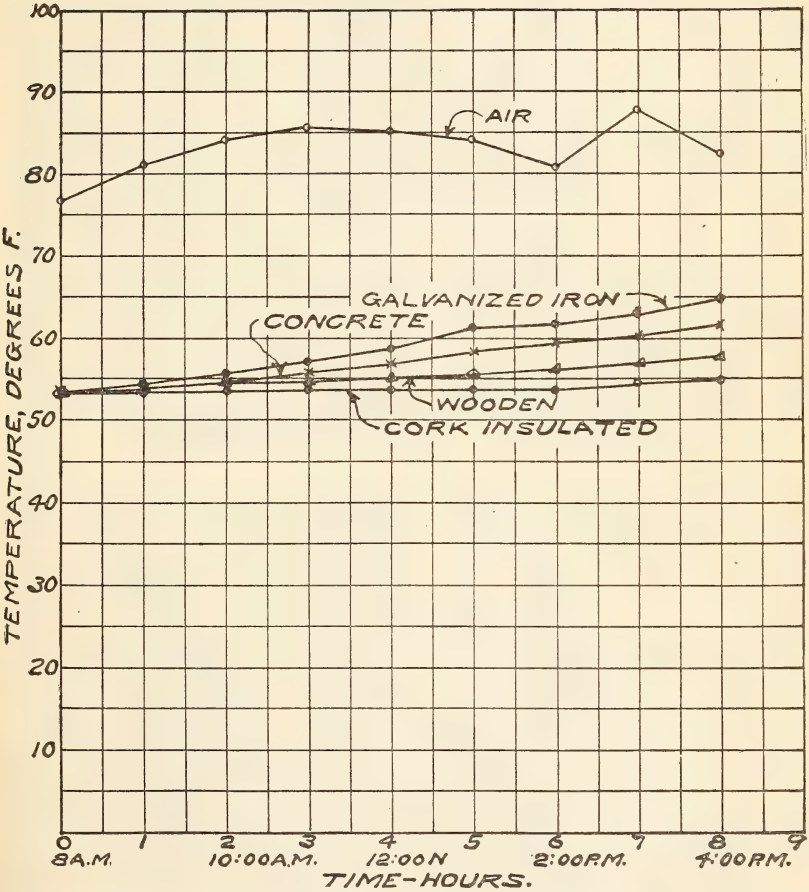

FIG. 10.—Rise in temperature of water during 9 hours in 4 types of cooling tanks. All tanks covered and in milk house.

lower than in the concrete tank, and 1½ degrees lower than in the wooden tank.

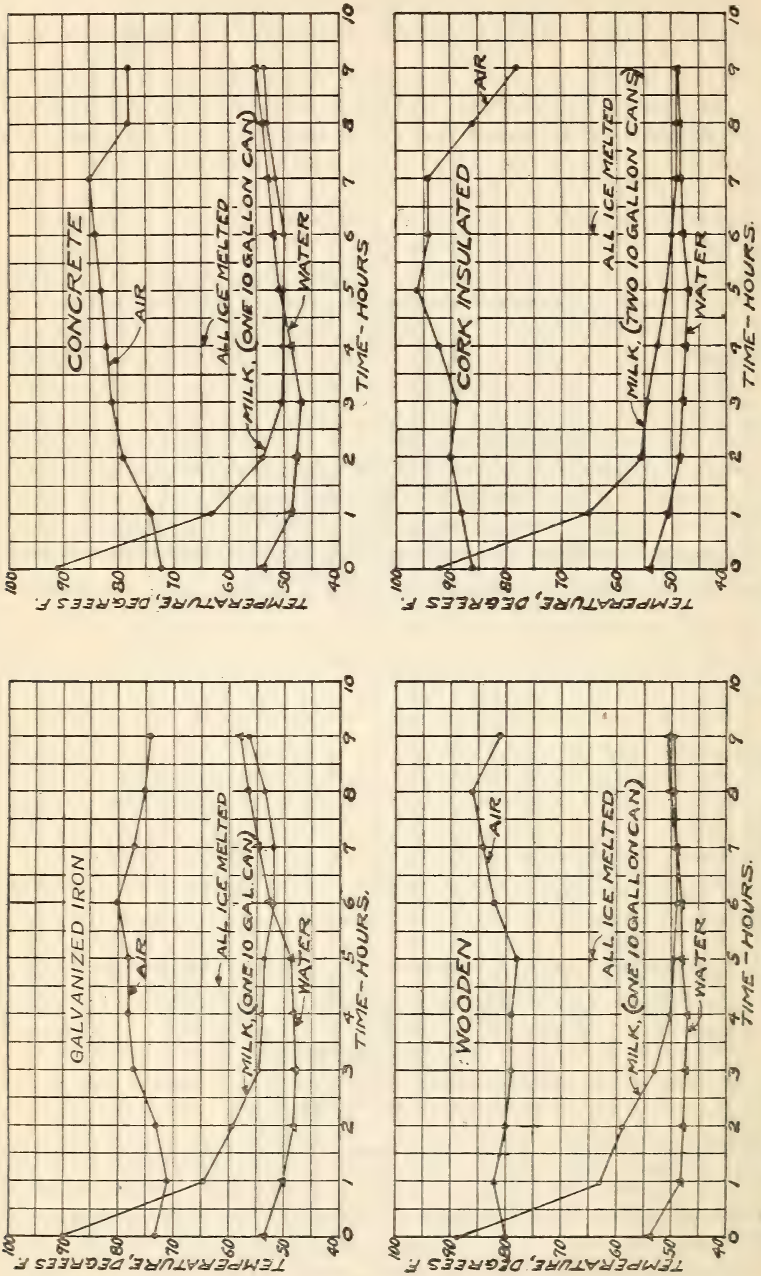

FIG. 11.—Variation in temperature of air, water, and milk in different types of tanks. All tanks covered and in milk house.

These tests illustrate the efficiency of the different tanks for cooling milk. Expressed in terms of ice melted the relative loss was 29 pounds for the insulated tank, 65 pounds for the wooden tank, 101 pounds for the concrete tank, and 126 pounds for the galvanized-iron tank.

THE CONSTRUCTION OF MILK TANKS.

Milk tanks should be so constructed as to minimize the loss in cooling effect through radiation from both water and ice. They should also be easy to construct, durable, and easy to clean. The best insulating materials are those that contain the greatest amount of entrapped air in the smallest space. Other factors, however, such as space occupied, structural strength, uniformity of insulating value, and ability to withstand moisture, should be considered in the selection of the insulating material. The material should not absorb moisture readily, because as soon as it is water-soaked its insulating value is impaired and it will rot. The insulation should be light, easy to work into place, and should occupy little space.

The height of the cooling tank depends upon the height of the cans to be used. Provision should be made so that the water on the outside of the cans will always be as high as the milk inside. An overflow pipe to regulate the height of the water, and a drainage outlet in the bottom of the tank so that the water may be emptied when it is desired to clean the tank, should be provided. Narrow strips on which to set the milk cans should be placed on the bottom of the tank in order to permit the water to flow under as well as around the cans. A frame should be made of 2 by 2 inch material, laid 2 inches apart, so that it will fit snugly in the bottom of the tank. It may be made to fit tightly by means of wooden wedges.

THE INSULATED CONCRETE TANK.

For use on the farm an insulated concrete tank will usually be found to be the most efficient and satisfactory in every respect. In building a tank of that kind the walls should have a total thickness of from 8 to 10 inches, divided into a 2 to 4 inch outer wall of concrete, next to which is placed a 2-inch layer of insulating material and an inside concrete wall of 4 inches. The concrete mix should consist of 1 part Portland cement, 2 parts clean, sharp sand, and 4 parts broken stone or gravel. Hydrated lime equal to 10 per cent by weight of the cement should be added to the mix for the purpose of making the tank waterproof. The outer wall should be constructed first, then the insulation should be set in hot asphalt or gas-house tar and its inner surface coated with the same material and allowed to dry thoroughly before the inner wall of concrete is built. The inside wall of the tank should be carefully troweled to force back all particles of stone or gravel, thus insuring a smooth inner surface.

In constructing the tank, if built partly underground as shown in figure 12, an outside form extending only from the surface of the ground to the top of tank is required. If built entirely above the ground a complete outside form is necessary. After the outside forms are in place pour 4 inches of concrete in the bottom. On this concrete set the inside form, leaving a space of from 2 to 4 inches between the forms, depending on the thickness of the outside wall. After the concrete is set remove the inside form and coat the inside walls and floor with hot asphalt or tar. The sheets of insulation should be coated also with the same material and put in place on the floor and against the walls, care being taken to make all joints tight. After the insulation is in place cut down the inside form, previously used, to a size that will provide a 4-inch space between the walls and forms. The form should be set in place and blocked up 4 inches above the floor, and the concrete for the inner walls and floor should be poured in one operation. The wooden curb around the top of the tank should have 20-penny spikes driven into the underside at frequent intervals and the curb set in place and pressed down so as to embed the spikes in the concrete before it sets. If the inner surface of the walls is rough upon removal of the forms, a plaster coat of cement mortar should be applied.

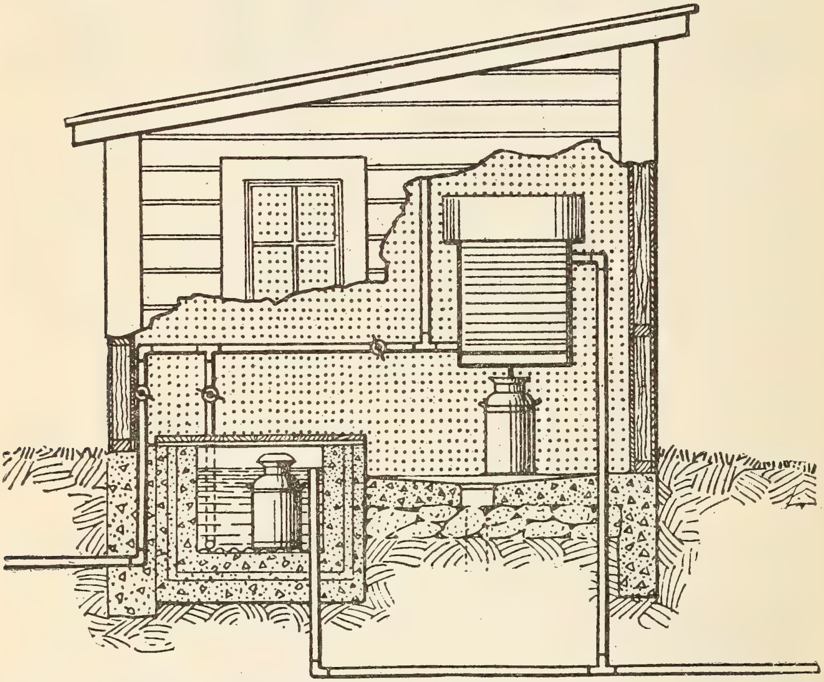

FIG. 12.—Arrangement of concrete-insulated cooling tank built partly below ground level.

DIVIDING THE TANK INTO A SMALL AND A LARGE COMPARTMENT.

The size of the tank depends upon the quantity of milk to be cooled. Frequently tanks are built of such sizes as to require an excessive quantity of ice for cooling. Since the quantity of milk produced on a dairy farm fluctuates from season to season and from year to year, it is advisable to construct a tank of two parts, the larger being approximately twice the size of the smaller. With a tank of that kind the larger part should be large enough to cool the quantity of milk ordinarily produced. The smaller part may be used in addition for handling an increased supply. In case production is decreased the smaller part can be used alone, thus insuring more efficient cooling. Such arrangements can be made with little additional expense at the time of building, and they result in more efficient cooling.

As an example of what may be accomplished by such an arrangement a test was conducted in which a 10-gallon can of milk at 91° F. was placed in a concrete tank containing 1,000 pounds of water at 54° F. to which a 100-pound block of ice had been added. The can was left in the tank from 8 a. m. until 5 p. m. on a day when the air temperature ranged from 75° to 85° F. At 5 p. m. the milk had a temperature of 53½° F. The same tank was afterwards divided into two parts, one being two-thirds and the other one-third the size of the original tank. Into the smaller part of the tank were placed 350 pounds of water at 54° F., a 100-pound block of ice, and a 10-gallon can of milk at 90° F. The air temperature during the 9 hours, from 8 a. m. to 5 p. m., ranged from 75° to 85° F., and during that time the milk was cooled to 48° F., or 5½ degrees lower than when cooled in the larger tank.

The test was repeated with a wooden tank, a can of milk at 90° F. being left for 9 hours in a tank containing 1,000 pounds of water with an initial temperature of 54° F. and a 100-pound block of ice. At the end of the 9 hours the milk had been cooled to 50° F. The tank was then partitioned in a manner similar to the concrete tank and a 10-gallon can of milk at 90° F. was placed in the smaller part, the quantity of water and ice used being the same as in the concrete tank. At the end of 9 hours the can of milk was cooled to 41° F., or 9 degrees lower than for a similar can in the large wooden tank. It is evident that for cooling efficiency a tank holding 3 or 4 gallons of water for each gallon of milk makes for more efficient use of ice than a larger tank.

LOCATION OF TANK.

For best results the cooling tank should be covered and placed in a building where it will be sheltered from the direct rays of the sun. The best location, therefore, is in the milk house. When a milk-cooling tank is placed outdoors, exposed to the action of the weather, there is usually a rapid deterioration and a great loss in cooling efficiency. Besides keeping milk cold a properly constructed cooling tank also protects it from dust, flies, and other contaminating influences.

HOW TO COOL MILK QUICKLY.

Much of the market milk for our large cities reaches the railroad station in the country for shipment at a temperature of about 60° F., and some is as high as from 80° to 90° F. At least one of our large cities obtains milk from a territory 400 miles away. It is evident, therefore, that milk on such a journey to the city has a considerable time in which to deteriorate in quality. The higher the temperature of the milk the sooner it will deteriorate. Because of the shortness of time between milking and the time of shipping, it is usually impracticable to cool all milk to below 50° F. on the farm by the use of a milk-cooling tank alone. Some sort of surface cooler must be used in addition if the milk is to be cooled to 50° F. before shipment. A surface cooler properly used with a supply of cold running water greatly reduces the quantity of ice needed in cooling milk to a definite temperature, and also insures more rapid cooling. Unfortunately much of the running water used in surface coolers becomes warmer before use, either by allowing it to flow above the surface of the ground, as from a spring, or by taking it from a storage tank exposed to the sun.

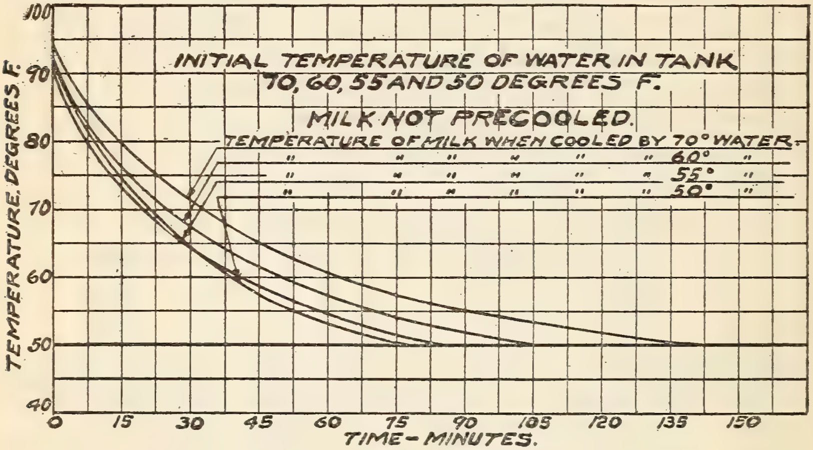

FIG. 13.—Time required to cool a 10-gallon can of milk to 50° F. under various conditions. Milk not precooled.

It is possible, by using a surface cooler to best advantage, to cool the milk to within 2 or 3 degrees of the temperature of the water. The colder the water, therefore, the more effective will be the cooling. A series of tests was conducted with water at different temperatures in order to determine the length of time necessary to cool milk to 50° F. In each test a 10-gallon can of milk was used. The milk was placed in an insulated tank containing from 75 to 80 gallons of water. Tests were conducted with water at 70°, 60°, 55°, and 50° F., respectively, and in each test a 300-pound block of ice was placed in the tank. The quantity of ice used was larger than is common for tanks of the size mentioned and consequently the time required to cool a 10-gallon can of milk to 50° was shorter than under most farm conditions. In the first test the air temperature was from 70° to 75° F. and the water had a temperature of 70° F. In the second test the air temperature was from 60° to 65° F. and the water 60° F. In the third test the water had a temperature of 55° F. and the air but 1 or 2 degrees higher. In the fourth test the air and water were both at about 50° F. Figure 13 shows the time required to cool milk to 50° F. under various conditions when the milk was not precooled with a surface cooler. In none of the tests was the milk stirred. The time required to cool the milk to 50° F. when the tank water was 70°, 60°, 55°, and 50° F., respectively, was 2 hours and 25 minutes, 1 hour and 45 minutes, 1 hour and 25 minutes, and 1 hour and 20 minutes.

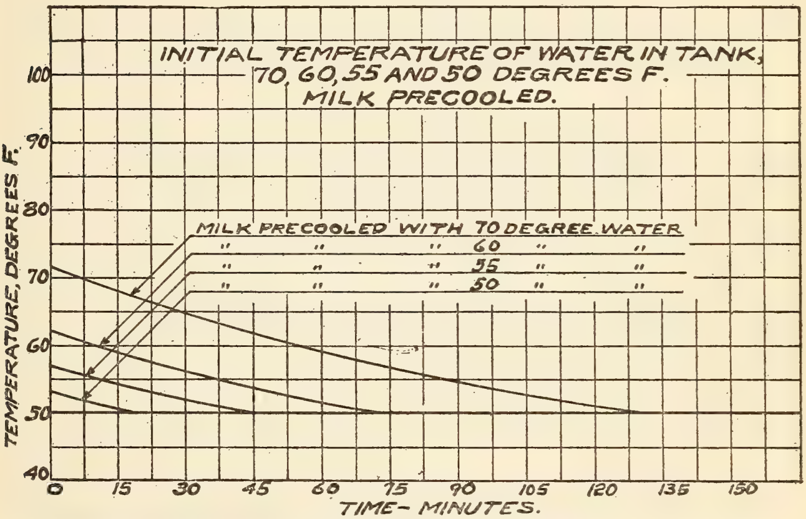

FIG. 14.—Time required to cool a 10-gallon can of milk to 50° F. under various conditions. Milk precooled.

It is evident that the time necessary to cool milk to 50° F. by these methods is too long for satisfactory use on dairy farms where the morning's milk must be delivered to the railroad station a short time after milking. It must be remembered also that an exceptionally large quantity of ice was used.

The effect of precooling milk with a surface cooler through which water circulates at temperatures of 70°, 60°, 55°, and 50° F., respectively, upon the length of time required to reduce it below 50° F. in a cooling tank is well illustrated in figure 14. When milk was precooled by water at 70°, 60°, 55°, and 50° F. the time necessary for cooling to 50° F. under conditions similar to those mentioned in the previous experiment was, respectively, 2 hours and 10 minutes, 1 hour and 15 minutes, 43 minutes, and 20 minutes. In terms of ice melted the precooling resulted in a saving of 11, 16, 19, and 22 pounds of ice, respectively.

An efficient way of cooling milk on a dairy farm is well illustrated in figure 15. Warm milk that was not precooled was placed in a tank containing water at 37° F. and was cooled to 50° F. in about an hour. The same quantity of milk precooled with water at 55° and then placed in a tank of ice water at 37° was cooled to 50° F. in 20 minutes. This illustrates an easy and rapid method of cooling milk to 50° F. or below if ice is used.

While, from a cooling standpoint, wooden tanks give good results, an insulated concrete tank similar to the one shown in figure 1 is more satisfactory for the dairy farm. A tank of that kind is not hard to construct, is very durable, and can be set partly in the ground, which is an advantage in that cans can be lifted in and out with less effort.

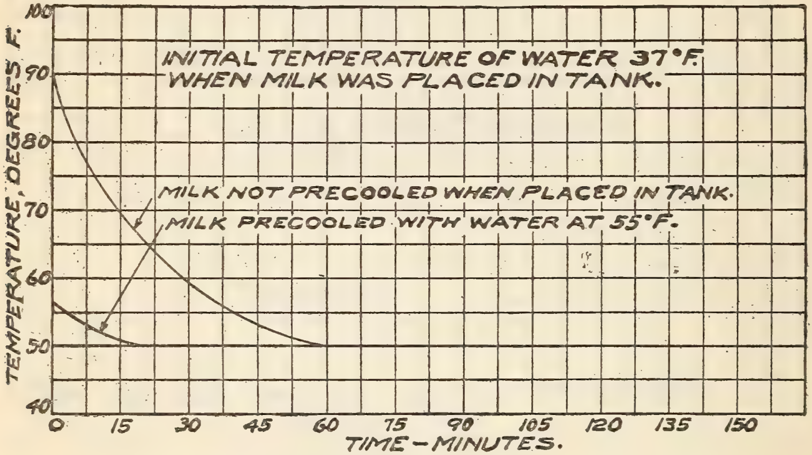

FIG. 15.—Showing quick method of cooling milk with ice water.

THE USE OF ICE.

For best results ice should be put into the cooling tank a sufficiently long time ahead of the cans of milk to insure that the tank water is at a low temperature when the cans of milk are set in. To insure that milk is cooled to and is held at a sufficiently low temperature, a cooling tank always should contain ice during hot weather. The quantity of ice necessary depends upon the outside temperature, the quantity of milk to be cooled, and the size, construction, and location of the cooling tank. The quantity necessary for any given set of conditions can be determined readily by putting a definite quantity of ice into the tank and using a thermometer to ascertain the temperature to which the milk is cooled. When milk is precooled by means of a surface cooler to between 52° and 62° F. and is placed in a cooling tank in which the temperature of the water is 45° F., from 1½ to 2 pounds of ice for each gallon is necessary to cool milk to and to keep it at 50° F. for a day. When precooling is not practiced and the tank water has a temperature of 45° F. about 4 pounds of ice per gallon will be necessary.

EFFICIENCY OF DIFFERENT TYPES OF CANS FOR HOLDING MILK.

In order to determine the relative value of different types of milk cans for maintaining low temperatures in milk held without agitation for a considerable period, a series of experiments was conducted. Six 10-gallon cans were used, as follows: Nos. 1 and 2 were insulated; No. 3 had an ice compartment; No. 4 was an ordinary can covered with 1-inch felt jacket; No. 5 was an ordinary can covered with a ½-inch jacket; and No. 6 was an ordinary milk can. The cans were placed in a room in which the temperature was maintained at 74½° F. The initial temperature of the milk in cans Nos. 1, 2, 3, and 4 was 35° F.; in No. 5 it was 36° F., and in No. 6 it was 37° F.—The milk was not stirred in any of the cans during the test, the temperature reading being taken by removing the top and inserting a long-stemmed thermometer into the center of the can. In each case formaldehyde enough was added to the milk to prevent premature souring.

The results of the test are shown in figure 16. It will be noted that the time required for the temperature of the milk to rise to 50° F. was as follows:

	Hours.		Hours.
Can No. 1	24	Can No. 4	22
Can No. 2	30	Can No. 5	18
Can No. 3	22	Can No. 6	11

It should be kept in mind of course that the initial temperature of the milk in can No. 5 was 36° F. and in can No. 6 37° F. Comparing the various cans with No. 6 (the bare, unprotected can) it will be noted that No. 1 took 2.18 times as long; No. 2 required 2.73 times as long; Nos. 3 and 4 required twice as long; and No. 5 required 1.63 times as long as No. 6 for the temperature of the milk to rise to 50° F. The results indicate the efficiency of the various methods of protecting cans in keeping milk at low temperatures.

In test No. 2 the conditions were similar to those in the first test except that the room temperature was 99.5° F., or 25 degrees higher, and the initial temperature of the milk in each can was 44° F. The relative time required for the milk to rise in temperature from 44° to 50° F. for the various cans was as follows:

	Hours.		Hours.
Can No. 1	8	Can No. 4	4
Can No. 2	10	Can No. 5	2
Can No. 3	3	Can No. 6	$\frac{3}{4}$

While the high temperature of 99.5° F. would not be encountered frequently in practice, it serves well to illustrate the efficiency of different types of cans under extreme conditions. In curve No. 3 of figure 17, showing the rise in temperature of milk in the ice-compartment can, it will be noted that all the ice was not melted until about 8 hours after the beginning of the test. The temperature of the milk, however, rose to 50° F. within 3 hours. The rapid rise in temperature of the milk in the can, even though the ice compartment contained ice, is due to the large surface which was exposed to the warm outside air as compared to the smaller surface exposed to the ice. The absorption of heat by the milk from the air was much faster than the absorption of heat by the ice from the milk. It will be noted that after all the ice was melted the rise in temperature of

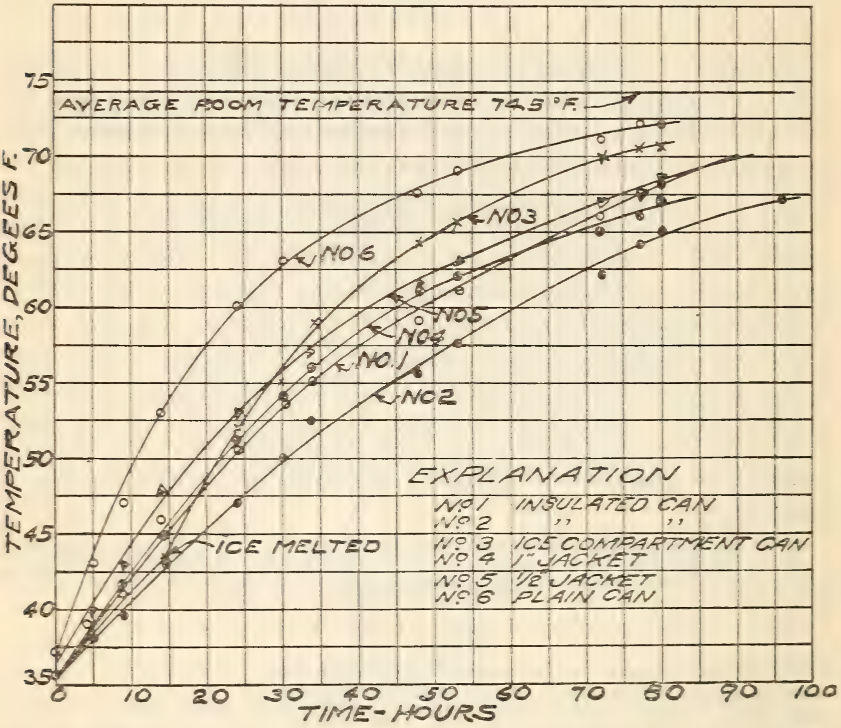

FIG. 16.—Efficiency of various types of cans for holding milk. Room temperature, 74.5° F.

the milk in the can was about the same as in the ordinary milk can, No. 6.

Comparing the time required for milk to rise in temperature from 44° to 50° F. with the ordinary can (No. 6), it will be found to be 10.7 times as long in can No. 1, 13.3 times in can No. 2, 4 times in can No. 3, $5\frac{1}{2}$ times in can No. 4, and 2.7 times in can No. 5. The importance of some sort of insulation for milk cans is apparent when milk is to be shipped considerable distances and reach its destination at a temperature below 50° F. This last experiment illustrates very well the rise in temperature which may be expected when milk is allowed to stand in the sun during very hot weather. Instances in which cans of milk are left for several hours without shelter or other protection either on the roadside or at the milk-receiving station, are too common to need comment.

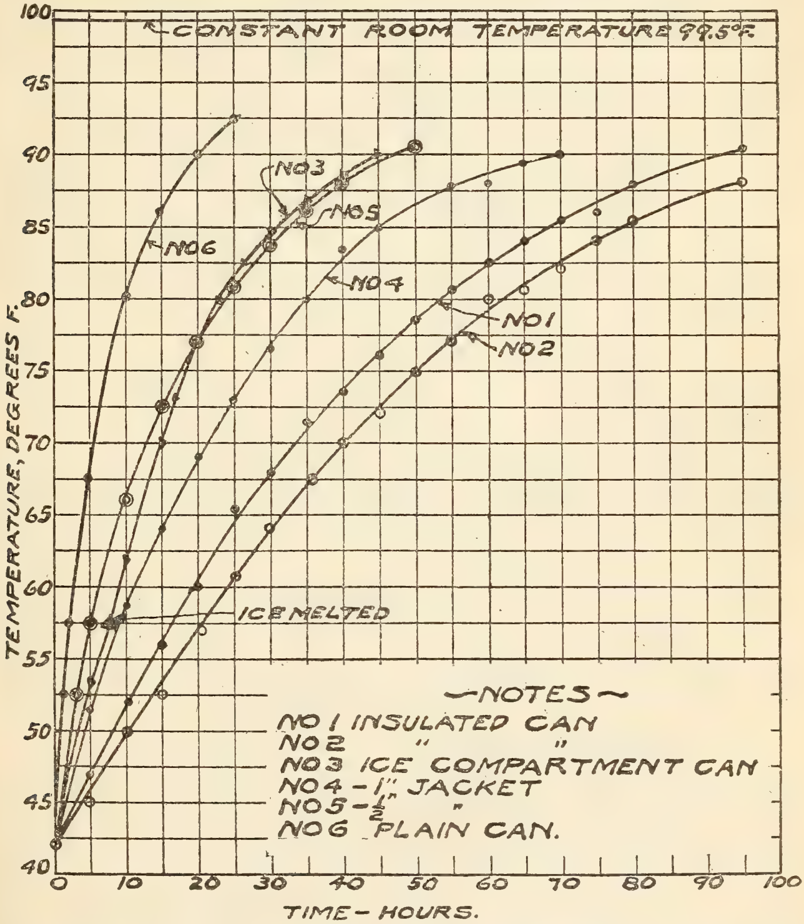

FIG. 17.—Efficiency of various types of cans for holding milk. Room temperature, 99.5° F.

In the northern section of the United States milk is frequently shipped to the city during the winter when the temperature of the air is below zero. Since milk freezes at a temperature between 31° and 29° F., it is important that some provision be made to prevent freezing in transit. A test, therefore, was conducted to determine the efficiency of the same cans used in the previous tests for preventing freezing. Because of the limited space in the refrigerator but two cans could be handled at a time. It was not possible to hold, therefore, all cans at exactly the same temperature during the test because of the difficulty in keeping the refrigerator at exactly the same temperature from day to day. The temperature of the refrigerator ranged from ¼° to 4½° F., the average temperature being about 2½ degrees above zero. The initial temperature of the milk, when the cans were placed in the refrigerator, was 77° F., and the cans were held until its temperature had reached 30° F. The drop in temperature is graphically shown in figure 18. The time required for the milk in the different types of cans to drop from 50° to 30° F. was as follows:

	Hours.		Hours.
Can No. 1	20	Can No. 5	16½
Can No. 2	21	Can No. 6	7
Can No. 4	18½		

Can No. 3, the ice-compartment can, was not used as it was not suitable for the experiment. Comparing the time necessary for the temperature of the milk to drop from 50° to 30° F. with that of the ordinary can (No. 6) we find:

Can No. 1 required 2.9 times as long.
Can No. 2 required 3.0 times as long.
Can No. 4 required 2.6 times as long.
Can No. 5 required 2.3 times as long.

The showing above indicates the efficiency of felt jackets or insulated cans for shipping milk in zero weather.

TRANSPORTING MILK AT LOW TEMPERATURES.

A large percentage of city milk supplies is delivered to the railroad station by the producers or is brought to the station by wagons or trucks which collect milk from several farms. A certain quantity of milk is hauled directly to the city by means of teams or motor trucks. Unless the milk is especially protected its temperature will rise several degrees in the journey from the farm to the station, and if afterwards in the haul of from a few hours to all day to the city it is exposed to high temperatures its temperature when it reaches the market is usually not low enough to prevent the rapid multiplication of bacteria. Much milk is transported to the city in ordinary baggage cars or in uniced milk cars. To insure its reaching the city in the best condition milk should be cooled on the farm to 50° F. or below and should be carefully protected during shipment to the city. The same precautions which prevent milk from becoming warm during shipment in summer also prevent it from freezing in the winter.

In some refrigerator cars it is possible to keep milk at a low temperature during shipment, but most of the milk is shipped in cars that frequently are opened in transit to receive new supplies, and in which the ice, if any is used, is placed on the top of the milk cans. Much of the cooling effect is lost when the cars are thus opened.

RESULTS OF EXPERIMENTAL SHIPMENTS.

To determine the relative efficiency of ordinary milk cans compared with jacketed and insulated cans in keeping milk cold during long shipments, three experiments were conducted as follows:

In the first experiment 4 of the 10-gallon cans used in the previous tests were employed, No. 1 being insulated, No. 4 having a 1-inch felt jacket, No. 5 having a ½-inch felt jacket, and No. 6 being the ordinary milk can. The cans were filled with milk cooled to 44° F. and were hauled in an open truck a distance of 13 miles from the farm to the railroad station. The air temperature during the 2½ hours' haul was about 80° F. Upon arrival at the station the cans were shipped in an ordinary baggage car which was opened in transit to receive and discharge baggage from Washington, D. C., to New Orleans, La., a distance of 1,120 miles.[1]

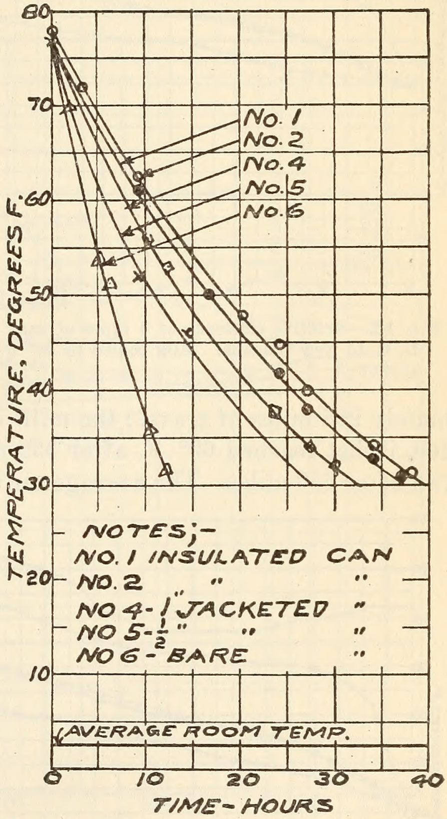

FIG. 18.—Efficiency of various types of cans for holding milk. Temperature near zero F.

The rise in the temperature of the milk and the temperature of the surrounding air during transportation was obtained by means of recording thermometers. Figure 19 shows the rise in temperature of the milk in each of the several cans, together with the air temperature during the trip. The milk in the ordinary can reached 60° F.

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[1] The shipment of milk was supervised by C. S. McBride, of the Dairy Division.

after it had traveled about 10 miles from the farm; the milk in the can covered with a ½-inch felt jacket reached 60° F. after approximately 268 miles of travel; the milk in the can covered with a 1-inch felt jacket reached 60° F. after 332 miles, and that in the insulated can after 650 miles. The average air temperature during the journey was 80° F. Compared with the ordinary can, the ½-inch jacketed can allowed milk to be shipped 26 times as far before it reached 60°

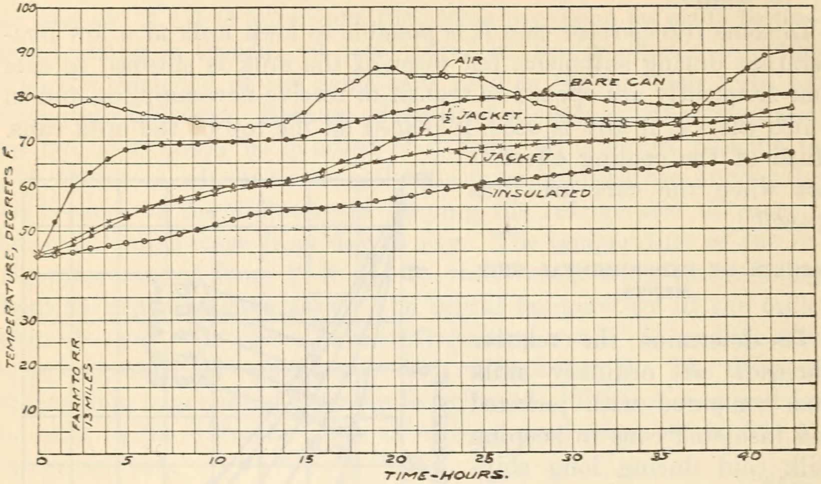

FIG. 19.—Relative efficiency of 4 types of cans in shipment of milk from Washington, D. C. to New Orleans. Milk cooled to 44° F. and hauled 13 miles in open truck to station.

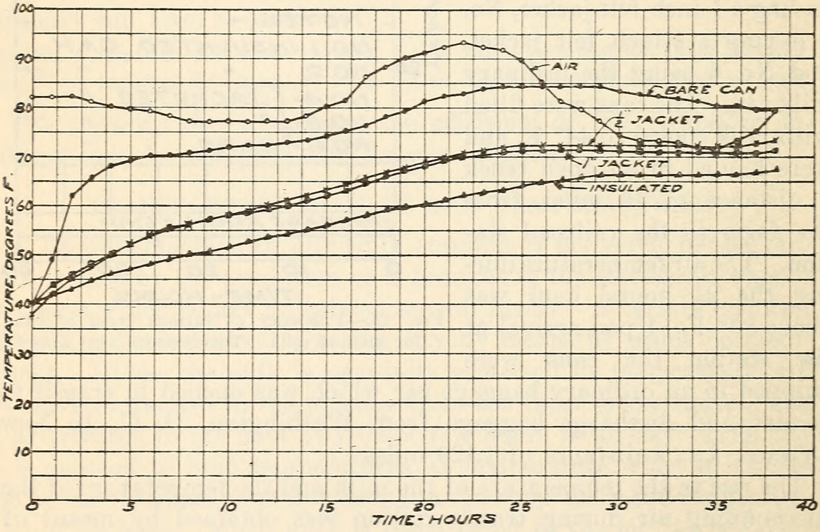

FIG. 20.—Relative efficiency of 4 types of cans in shipment of milk from New Orleans to Washington, D. C. Milk cooled to 40° F. and loaded directly at railroad station.

F.; the milk in the 1-inch felt jacketed can traveled 33 times as far; and that in the insulated can 65 times as far.

In the second experiment the same cans were used and the other conditions were the same, except that there was no country haul and the milk was cooled to 40° F. before being started on its journey. The results are shown graphically in figure 20. The milk in the ordinary can reached a temperature of 50° F. after traveling about 75 miles; that held in the ½-inch jacketed can after 355 miles; that in the can covered with the 1-inch felt jacket after 385 miles; and that in the insulated can after 605 miles.

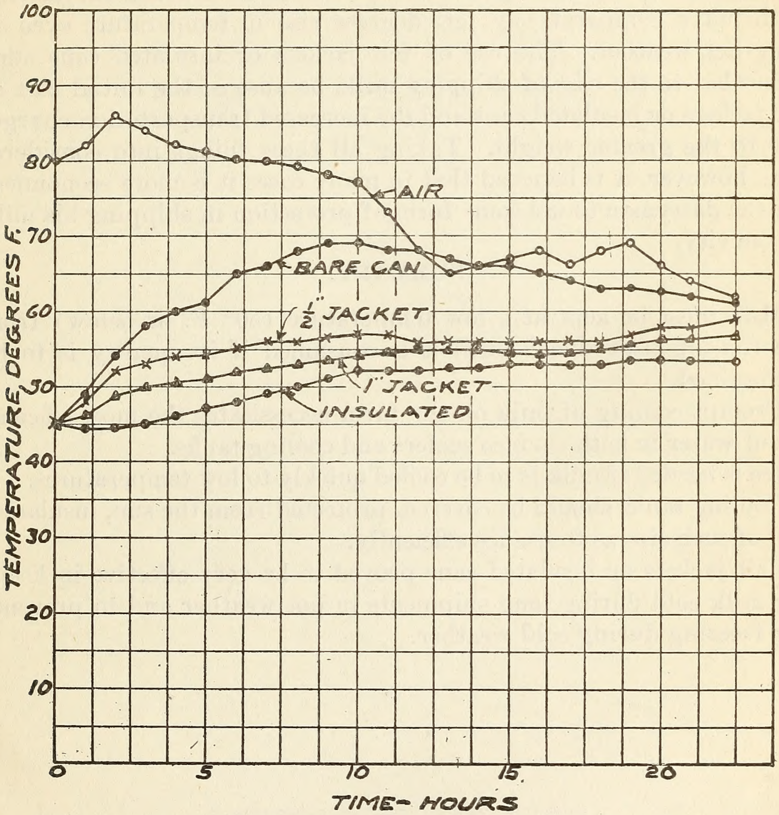

FIG. 21.—Relative efficiency of four types of cans in shipment of milk from Chicago to Washington, D. C.

In the third experiment 4 similar cans of milk were shipped from Chicago, Ill., to Washington, D. C., a distance of 787 miles,[1] in an ordinary baggage car. As in the previous experiments the doors were opened at stations to receive and deliver baggage. The data obtained in this experiment are shown graphically in figure 21.

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[1] This shipment of milk was supervised by R. S. Smith, of the Dairy Division.

The milk was 22½ hours in transit and the average air temperature of the baggage car was about 73° F. The temperature of the milk in the different cans was between 44° and 45° F. when placed in the car. This test demonstrates that the temperature of milk upon its arrival at destination is no indication of the temperatures which it has experienced in transit and that jacketed and insulated cans prevent rapid fluctuations in temperature.

When milk is cooled to between 40° and 45° F. on the farm, it may, through the use of felt jackets or insulated cans, reach the market with but a comparatively few degrees rise in temperature even in very hot weather. The use of felt jackets or insulated cans adds somewhat to the cost of shipping milk, because of the initial cost of the jackets or insulated cans and the increased transportation charges due to the greater weight. Taking all these things into consideration, however, it is believed that in many cases it is more economical for the dairyman to use some form of protection in shipping his milk to the city.

SUMMARY.

Milk must be kept at a low temperature (50° F. or below) from the time it is produced until it is consumed if its quality is to be maintained.

Prompt cooling of milk on the farm necessitates the most efficient use of water in both surface coolers and cooling tanks.

Ice is needed if milk is to be cooled quickly to low temperatures.

Cooling tanks should be covered, protected from the sun, insulated, and of such size as to use ice efficiently.

Felt jackets or insulated cans proved to be very effective in keeping milk cold during long shipments in hot weather and in preventing freezing during cold weather.

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